Water & Energy Use in Steam-Heated Buildings

By Ian Shapiro, P.E.

An anecdotal report of high energy savings at a multifamily building in Ithaca, N.Y., resulting from the replacement of an old steam boiler with a new hot water (hydronic) boiler, led to a survey of similar completed projects in New York to assess if these high savings have been delivered elsewhere. Four projects were identified in which old steam boilers were replaced with new hydronic boilers. Savings were significant for all four, averaging 40.5% of total heating use (exceeding predicted average savings).

By comparison, three projects were identified where old steam boilers were replaced with new steam boilers. Savings were poor, averaging only 0.6% of total heating use and falling far short of predicted average savings. Overall energy use was compared in a larger sample of buildings and found to be 24% higher in buildings heated with steam.

An evaluation of water use in steam-heated buildings was conducted. Fifty buildings were surveyed for which water use records were available. Water use in steam-heated buildings was found to be 79% higher than in buildings not heated with steam, and was almost twice the national average for residential water consumption per person. This difference works out to be 58.2 gallons (220 L) per person per day in water use. The potential waste of water (for example, almost 6,000 gallons [22 712 L] per day in an apartment building with 100 occupants) points to the dramatic energy and water conservation potential in converting steam systems to hydronic heating systems.

Energy Use

Steam heating systems, first developed well over 100 years ago, are still surprisingly widely used in residential, commercial, and industrial buildings. For example, steam systems represent the majority of buildings participating

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in the Multifamily Performance Program (MPP), a New York State energy-efficiency program for multifamily buildings. A survey of 63 buildings in the program found 46 (73%) to be heated with steam boilers, and six other buildings (9.5%) to be heated with purchased district steam, for a total of 82.5% of the buildings heated with steam. Of these 52 steam-heated buildings, 32 have two-pipe distribution, 10 have one-pipe distribution, and 10 have hydronic distribution systems through the use of steam-to-water heat exchangers. Most of the buildings are more than 20 years old, but the tradition of steam heat is so strong that even relatively new buildings, as recent as five years old, have been found to be designed and built with steam heating systems.

These steam heating systems appear to make their buildings energy intensive. In the previous sample of 63 buildings, source energy use intensity (overall building energy use, including power plant fuel, reported in energy audits for each building participating in the program) in steam-heated buildings averaged 159 kBtu/ft^2·yr (1 805 687 kJ/[m^2·yr]), 24% higher than the 128 kBtu/ft^2·year (1 453 635 kJ/[m^2·yr]) average for buildings not heated with steam. Although the source energy use combines heating use with hot water and electricity, the difference is certainly large enough to draw attention, especially because the buildings were all residential with five or more units (a building type for which non-heating energy uses should be at least somewhat comparable).

Prior studies have shown energy savings from converting steam heating systems to hydronic systems.[1, 2] A more recent study confirms that buildings with steam heating distribution systems have far higher heating fuel intensities (18.2 and 14.5 Btu/ft^2 HDD [206 689 and 164 670 J/m^2 KD] for one-pipe and two-pipe steam, respectively) than non-steam systems (5.4, 12.5, and 8.3 Btu/ft^2 HDD [61 325, 141 957, and 94 259 J/m^2 KD] for electric, hydronic, and hot air systems, respectively).[3]

Case Studies of Seven Boiler Replacements

Building Characteristics

Preretrofit and post-retrofit utility bills were analyzed for seven multifamily residential buildings where old steam boilers were replaced and for which utility bills were available. Six of the seven had participated in a program of the New York State Energy Research and Development Authority (NYSERDA). Three buildings had old steam boilers replaced with new steam boilers, and four buildings had old steam boilers replaced with new hydronic boilers (and associated distribution system changes). The boiler replacements occurred in the period between 1996 and 2008. Summary characteristics of the buildings are shown in *Table 1*. Heating system characteristics of the case study buildings are shown in *Table 2*.

Sites S2H-3 and S2H-4 had a complete steam-to-hydronic conversion. At both sites existing two-pipe radiators, as well as much of the existing piping were retained and reused. Condensate return piping was replaced in both buildings. For the other five systems, the distribution systems were repaired as needed, but not replaced. S2H-1 and S2H-2 originally had steam boilers, hydronic distribution, and a heat exchanger to couple them, which was discarded in the conversion.

Fuel Savings

Predicted and actual fuel savings are shown in *Table 3* with the predicted savings taken from energy audits and the actual savings from pre- and post-retrofit fuel bills.

Unlike the findings mentioned previously for total source energy use, savings are shown here as percent of original heating use, not as a percent of total fuel use. Base load use, such as domestic hot water or gas appliance use, was subtracted out before savings were calculated. Predicted savings were not available for site S2H-3 because this project did not have an energy audit. All actual preretrofit and post-retrofit heating use is weather normalized.

	Steam-to-Steam Conversions				Steam-to-Hydronic Conversions				
Building	**S2S-1**	**S2S-2**	**S2S-3**	**Average**	**S2H-1**	**S2H-2**	**S2H-3**	**S2H-4**	**Average**
Stories	6	5	10	7	12	11	3	3	7.3
Apartments	54	10	80	48	361	116	12	656	286.3
Number of Buildings	1	1	1	1	1	1	1	76	19.8
Type	Market Rate	Assisted	Market Rate		Market Rate	Market Rate	Market Rate	Assisted	

***Table 1:** Building characteristics for seven buildings in New York state.*

In most cases, non-boiler energy conservation measures (ECMs) were minor, or there were none at all. Where non-boiler energy conservation measures had been implemented, corrections were made to the savings calculations using data from the original energy audit.

Site S2H-4 probably represents a worst-case scenario (best case for fuel savings), as the boiler plant serves multiple buildings, and was known to have an old and leaky distribution system, including underground interbuilding distribution leaks. Other benefits accrued from the conversion to a hydronic system. The improvement reduced operations and maintenance costs due to the elimination of leaks. As the new system runs entirely on natural gas, it eliminated environmental concerns and liabilities related to the use of coal at the central plant.

Fuel Use Analysis

Actual savings from converting to hydronic boilers are far higher (40.5% average) than savings from replacement with new steam boilers (0.6% average).

Actual savings from conversion to hydronic boilers (40.5% average) exceed projected savings (31% average). Actual savings from replacing old steam boilers with new steam boilers (0.6% average) are less than projected (11.3% average).

	Steam-to-Steam Conversions			Steam-to-Hydronic Conversions			
Building	**S2S-1**	**S2S-2**	**S2S-3**	**S2H-1**	**S2H-2**	**S2H-3**	**S2H-4**
Fuel, Preretrofit	#4 oil	#2 oil	#6 oil	Gas	Gas	Gas	Gas & Coal
Fuel, Postretrofit	#2 oil	#2 oil	#6 oil	Gas	Gas	Gas	Gas
Distribution, Preretrofit	2-Pipe Steam	1-Pipe Steam	2-Pipe Steam	Hydronic	Hydronic	2-Pipe Steam	2-Pipe Steam
Distribution, Postretrofit	2-Pipe Steam	1-Pipe Steam	2-Pipe Steam	Hydronic	Hydronic	Hydronic	Hydronic

Table 2: Comparison of heating system characteristics for the sample buildings.

The sites with the highest savings (S2H-3 at 49.8% savings, and S2H-4 at 48.2% savings) are the ones with a complete steam to hydronic conversion. In other words, the preretrofit distribution systems were steam, and the entire systems were converted to hydronic. At S2H-3 and S2H-4, existing two-pipe radiators, as well as much of the existing piping were retained and reused. Condensate return piping was replaced in both buildings. The higher savings relative to systems where the preretrofit distribution system was already hydronic point to distribution leaks or other distribution losses as a significant contributor to steam system inefficiencies.

However, one site (S2H-1) had savings that were still substantial (41.2%), although its pre-retrofit distribution system was already hydronic. And, the other similar system (S2H-2) also had significant savings (22.6%). So, substantial savings appears to be possible even with a preexisting hydronic distribution system where only the boiler is replaced. This finding points to substantial boiler room losses.

Are Steam Leaks a Possible Cause of System Inefficiency?

Why do the conversions to hydronic heating from steam systems deliver more savings than expected, and the conversions to new steam boilers deliver lower savings?

- Steam systems are hotter than typical hydronic systems, with higher conductive losses.
- Steam systems are open to the atmosphere, so there are venting losses. Steam system leaks can be less evident because steam can escape directly to the atmosphere rather than leaking as water. Conversely, hydronic system water leaks are often immediately evident, and are usually repaired immediately.
- New steam systems are less efficient than new hydronic systems. They also have limits to outdoor reset control. Hydronic systems can be run cooler during swing seasons.

The findings of the seven boiler conversions (hydronic conversions generating savings higher than predicted and steam boiler replacements generating savings lower than predicted) possibly point to distribution losses as being an important component.

To evaluate whether steam systems might have higher steam or water leak rates than hydronic systems, total water use for steam-heated buildings was compared to buildings without steam heat (hydronic, electric, or forced air). This was done for a sample of buildings for which water use and occupancy data was available from the same NYSERDA multifamily program database. For 23 steam-heated buildings, water use averaged 132.1 gallons (500 L) per person per day; whereas for 27 buildings not heated with steam, water use was found to be 73.9 gallons (280 L) per person per day.

The American Water Works Association (AWWA) found the national average U.S. indoor water use to be 69.3 gallons (262 L) per person per day,[4] which is very close to the 73.9 gallons (280 L) per person per day seen in our study for buildings not heated with steam. At 132.1 gallons (500 L) per person per day, average water use at the steam-heated buildings is 79% higher than at the buildings we surveyed that are not heated with steam, and 91% higher than the national average as reported by AWWA.

Results were subjected to a test for statistical significance. Although the data for steam buildings shows more scatter with a higher standard deviation (84.7 compared to 16.5 for non-steam buildings) the confidence interval for the difference between the mean water consumption rates (132.1 for steam-heated buildings, 73.9 for non-steam buildings) confirms a statistically significant difference in water consumption between steam-heated buildings and non-steam-heated buildings, with 95% confidence. Only one type of steam heating system, the vacuum system, appears not to use more water. A small sample of four such buildings averaged 45.1 gallons (171 L) per person per day water consumption.

These findings, which implicate steam systems in high water use, are supported by data from two of the case study sites for which preretrofit and post-retrofit water use is available. Site S2H-4 showed a 26% decrease in water use after replacing a steam boiler system with a hydronic system. Water cost savings increase overall cost savings by 17% for the project (when added to energy cost savings). By contrast, site S2H-1 with preretrofit hydronic distribution only showed a 4% decrease in water use after replacing a steam boiler with a new steam boiler. We speculate that steam losses are lower where the preretrofit distribution system was hydronic. Steam losses were limited to the boiler room. Therefore, water savings for this system were lower.

Conclusions

Steam-heated buildings were found to use more water than buildings not heated with steam (almost twice the national

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average, on a per person basis), serving as a likely explanation of why converting buildings from steam heat to hydronic heat was found to save more energy than expected, while replacing old steam boilers with new steam boilers was found to save less energy than expected.

	Steam-to-Steam Conversions				Steam-to-Hydronic Conversions				
Building	S2S-1	S2S-2	S2S-3	Average	S2H-1	S2H-2	S2H-3	S2H-4	Average
Predicted Savings	6.8%	21.0%	6.0%	11.3%	24.1%	16.7%	NA	52.0%	30.9%
Actual Savings	–12.4%	4.1%	10.0%	0.6%	41.2%	22.6%	49.8%	48.2%	40.5%

Table 3: Savings for steam-to-steam conversions, as compared to steam-to-hydronic conversions.

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